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LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

PROGRESS REPORT

by

L. Lesensky - C.R. McGeoch

OCTOBER 1966

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

Contract DA28-043-AMC-01698(E)

RAYTHEON COMPANY

MICROWAVE AND POWER TUBE DIVISION

Waltham, Massachusetts

ERRATA

Page 17 Figure 11 Delete solid dots and curve segment connecting them.

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LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

Third Quarterly Report

15 April to 15 July 1966

Report No. 3
Contract No. DA28-043-AMC-01698(E)
DA Project No. 7900-21-223-12-00

Prepared by

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For

U.S. Army Electronics Command
Fort Monmouth, N.J.

This research is a part of Project DEFENDER, sponsored by the Advanced Research Projects Agency Department of Defense, under Order No. 345, and is conducted under the technical guidance of the U.S. Army Electronics Command, Fort Monmouth, N.J.

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ABSTRACT

Based on microscopic examination of samples sputtered in the Ion Bombardment Vehicle (IBV), as well as measurements and observations of these samples in the Secondary Emission Test (SEE) Vehicle, the following conclusions as to ion bombardment effects were reached:

1) 30% Mo - 70% Al_2O_3 films on Mo substrate exhibited a sputtering rate of 0.007 molecules of Al_2O_3 per nitrogen ion at 1 ma/cm^2 and 650 volts.

2) Two hours of nitrogen sputtering of an impregnated tungsten sample at 2 ma/cm^2 and 1.8 KV increased the apparent porosity of the surface from 15% to 47%, compared to a bulk value of approximately 20%.

3) Sputtering had no effect on δ of Pt, while sputtering at 2 ma/cm^2 and 2 KV for 1-2 hours reduced δ by approximately 10% for the nickel cermet and impregnated tungsten samples.

Maximum secondary emission ratios of 3.5 and 4.3 were measured respectively for a GaAs and a 200Å CVD BN sample.

Measurements in the Electron Bombardment Vehicle (EBV) demonstrated the following:

1) A secondary emission ratio maximum of 3.6 could be maintained for a 500Å thick 30% Mo - 70% Al_2O_3 film on a Mo substrate, under electron bombardment at 0.5 Amp/cm^2 and 1200 volts, by maintaining an oxygen partial pressure of 6×10^{-7} Torr using a CuO oxygen source.

2) δ measurement in the EBV is approximately 15% low and is not affected by barium evaporation from the impregnated tungsten gun cathode.

Electron diffraction measurements showed that δ of the molybdenum-doped alumina films was reduced by the agglomeration of the Mo component to aggregates several hundred atoms in size.

Preliminary evaluation of the use of an auxiliary oxygen source in the CFA test vehicle with an aluminum cathode demonstrated the following:

1) Oxygen removal from cathode surface during tube operation is responsible for degradation of δ.

2) An auxiliary oxygen source can retard the cathode depletion rate.

3) Cathode activation due to oxygen is more rapid with the high voltage off.

4) Faster depletion rate during CFA operation than observed in EBV under electron bombardment conditions.

FOREWORD

Long-life cold cathode studies for crossed-field tubes are authorized by the United States Army Electronics Command, Fort Monmouth, New Jersey, under DA Project No. 7900-21-223-12-00. The work was prepared under the support of the Advanced Research Projects Agency under Order No. 345 and is conducted under the technical guidance of the U. S. Army Electronics Command, Fort Monmouth, N. J. 07703.

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1. INTRODUCTION

The objective of the present cold cathode study program is to achieve long life cold cathode performance for crossed-field amplifiers. This program is being performed for the United States Army Electronics Command, Fort Monmouth, New Jersey, under contract DA-28-043-AMC-01698 (E).

In this study, selected cold cathode materials will be evaluated as to: their secondary emission properties, their ability to withstand environmental factors expected in a crossed-field amplifier, and their crossed-field amplifier performance. Based on the above experimental information and pertinent theoretical calculations, a life prediction chart will be established for a number of cold cathode materials.

The program is divided into two concurrent phases, phase A being concerned with the measurement of various pertinent properties of cold cathode materials outside of the tube environment, and phase B involving the evaluation and life testing of selected cathodes in a crossed-field amplifier.

The first quarterly report of this contract (Technical Report ECOM 01698-1) contains a discussion of the objectives and plans for the over-all program.

2. PHASE A - MATERIALS EVALUATION

2.1 Ion Bombardment Effects. The Ion Bombardment Vehicle (IBV) constructed during the second quarter (See Figure 1) was used to evaluate the effects of ion bombardment on various candidate cold cathode materials. After ion bombardment in the IBV the samples were observed using a high-power microscope. They were then mounted in the secondary emission test vehicle (SEE vehicle) where observations as to secondary emission ratio and fluorescence were made.

The IBV was operated with nitrogen at approximately 10^{-3} Torr. Under these conditions ion bombardment current densities of 1 and 2 ma/cm^2 were used to sputter the following target materials: Pt, 30% Mo - 70% Al_2O_3 film on Mo substrate, impregnated tungsten, and nickel cermet.

2.1.1 Pt. A Pt target was sputtered at a current density of 1 ma/cm^2 and a voltage of 2 kv for 1 hour. Under the design conditions of the IBV only a 3/16 in. diameter central portion of the 3/8 in. diameter target was sputtered. The sputtered region had a dull, etched appearance as compared to the shiny unsputtered region. Under microscopic examination (400X magnification) it was observed that the sputtered region was highly decorated with many edge and screw dislocations, evidently due to selective sputtering at the surface.

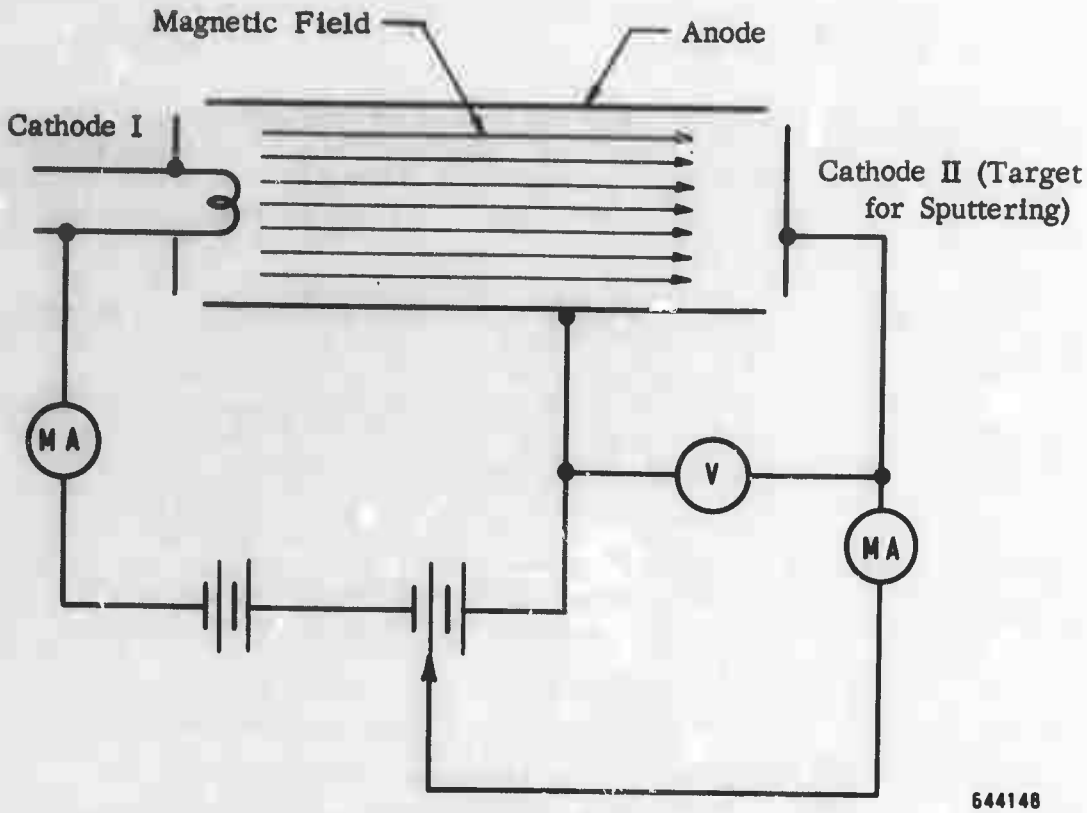

Figure 1. Schematic of Sputtering Apparatus

2.1.2 30%Mo - 70% Al_2O_3 films on Mo substrate. A 200 Å film was sputtered at 1 ma/cm^2 and 800 volts for 20 minutes. After 10 minutes the central sputtered region was only partially removed. After 20 minutes however, the film was completely sputtered away. Following this a series of six 1000 Å films were sputtered at 1 ma/cm^2 and 650 volts for various times up to a maximum of 90 minutes. The central sputtered region showed progressive color changes indicating the reduction in film thickness with complete erosion occurring after 90 minutes. A simplified sketch of the film after 90 minutes of sputtering is shown in Figure 2 . A central portion shows the Mo substrate where the film has been completely eroded away. Surrounding this region are successive colored rings which are similar to those films which had been sputtered for shorter time periods. The colored rings in Figure 2 are enlarged out of proportion for purposes of clarity.

Another set of six 1000 Å films were sputtered at 2 ma/cm^2 and 1100 volts, the results being quite similar to the previous set except that it took about half as much time to sputter through to the substrate material.

An estimate was made of the sputtering yield of Al_2O_3 from the above data. By neglecting the Mo component, one obtains a yield of 0.007 molecules/ion at 650 volts for nitrogen. This is in reasonable agreement

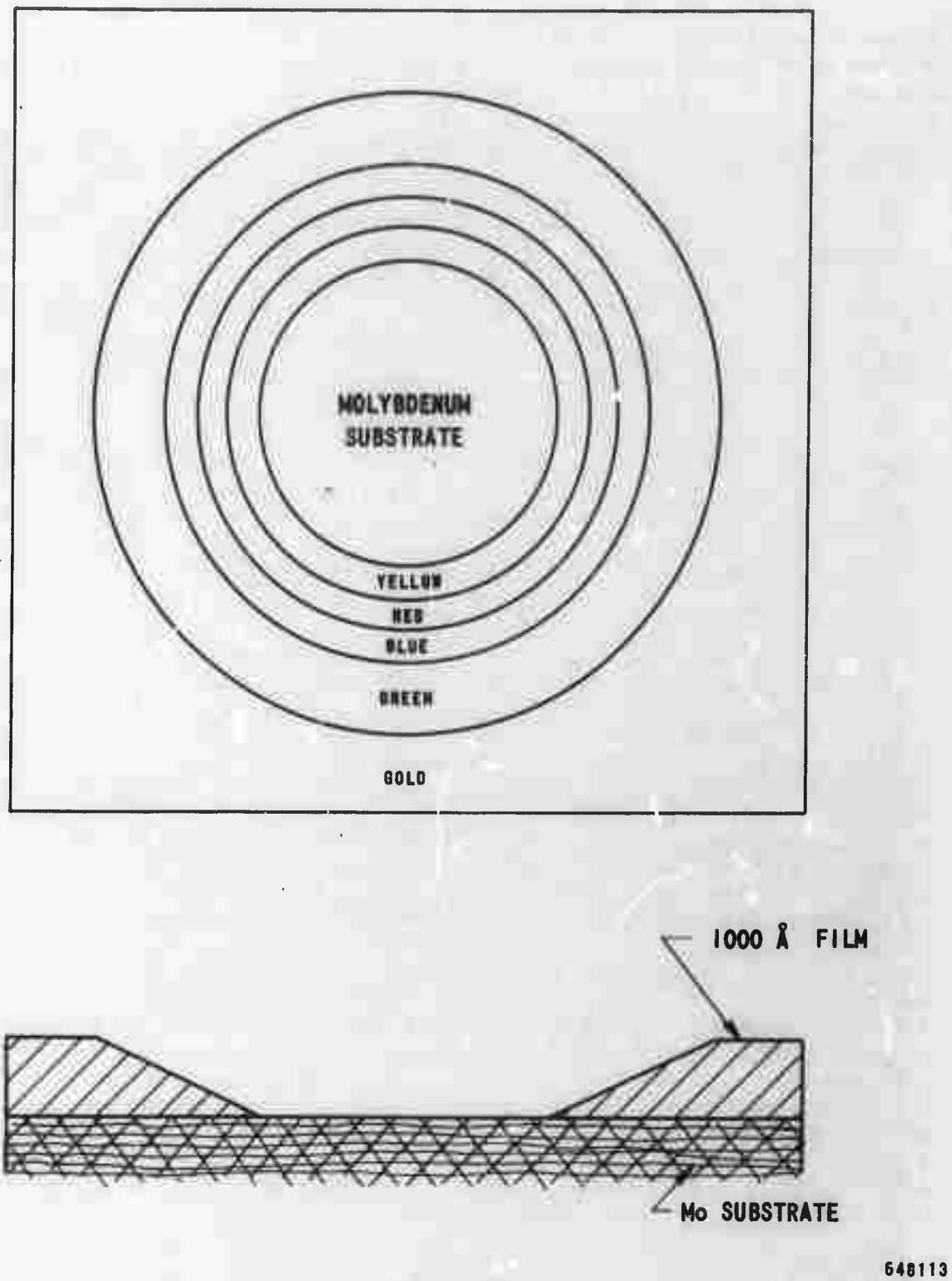

Figure 2 Sputtered 1000 Å Film of 30% Mo - 70% Al_2O_3 on Mo Substrate

with a value of yield, S = 0.016 molecules/ion, deduced from the data of Wehner et al[1] for the Hg sputtering of Al_2O_3 at 650 volts, when we apply a correction factor of 0.47* to adjust the value to N_2 sputtering of Al_2O_3. The mean free path of N_2 at 25°C and p = 10^{-3} Torr is approximately 5 cm. Therefore the error due to the backscattering of sputtered neutrals is not expected to be large.

Based on a depletion time of 90 minutes for a 1000 Å film subjected to an ion bombardment current density of 1 ma/cm^2 at 650 volts, one can project a film life of 50 hours at 0.03 duty cycle operation. However, the average ion bombardment current density in the CFA is estimated to be only ~ 10 μamps/cm^2. Based on this assumption, the sputtering life of the 1000 Å film in the QK1319 CFA test vehicle, operating at a duty cycle of 0.03, would be approximately 5000 hours.

2.1.3 Impregnated Tungsten. Two impregnated tungsten samples were sputtered at 2 ma/cm^2 and 1.8 KV. These samples were similar to some of those described in the 2nd quarterly report (p. 5) and had the following compositions:

sample no. 1 - 4 $BaCO_3$: 1 $CaCO_3$: 1 Al_2O_3
faster activating type

sample no. 2 - 3.5 $BaCO_3$: 1 $CaCO_3$: 1 Al_2O_3
slightly slower activating type.

Sample no. 1 was sputtered under the above conditions for 2 hours, while sample no. 2 was sputtered for only 1 hour. The results were qualitatively similar with sample no. 1 showing a more pronounced effect. In each case only a central region approximately 3/16 in. in diameter was sputtered so that each sample contained both sputtered and unsputtered regions. Figures 3 and 4 show a comparison of a sputtered and an unsputtered portion of sample no. 1 at a magnification of 210X. In each photograph, the white areas are interpreted as representing reflecting metallic tungsten areas. The dark areas probably represent depressions in the surface, whose bottoms may be filled either with impregnant or with tungsten. The samples had been polished initially to a final polish using 4/o emery paper. Typically, this type of polishing results in the removal of impregnant, leaving depressions in the surface. An analysis of the photograph of the unsputtered region showed the dark area to cover 15% of the surface. This is in reasonable agreement with the usual 20% porosity of the tungsten matrix. A similar analysis of the sputtered region revealed a 47% dark area coverage of the surface. It is supposed that the sputtering of the surface loosened additional tungsten particles ** revealing more depressed areas.

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* This factor is obtained from data for sputtering copper with N_2 and Hg.

** Some metallic dust was found at the bottom of the IBV.

Figure 3. Impregnated Tungsten Sample No. 1 Sputtered at 2 ma/cm^2 and 1.8 KV (210X Magnification)

Figure 4. Impregnated Tungsten Sample No. 1 Unsputtered (210X Magnification)

2.1.4 Nickel cermet. Two nickel cermet samples were sputtered at a current density of 2 ma/cm^2 and a voltage of 2 KV for one hour. Each had the same composition, namely 70% Ni and 30% Radio Mix No. 3.* One of the samples was polished down using 4/o emery paper; the other, was left unpolished. Both samples showed a darkening of the center of the sputtered region. The polished one was subjected to microscopic examination. Figure 5 shows a comparison of the sputtered and unsputtered regions** at a magnification of 80X. It is supposed that the initial polishing caused the soft nickel to smear over the areas containing Radio Mix No. 3 and that the sputtering eroded away the smeared-over Ni film. It was also possible to detect many pits in the light areas (metal) of the sputtered region; these were not present in the unsputtered regions.

Secondary emission measurements were then made of the sputtered samples of Pt, the impregnated tungsten samples, and both the polished and unpolished Ni cermet samples. The results are described in Section 2.2.

2.2 Secondary Emission Measurements

2.2.1 Sputtered Samples. After being sputtered in the IBV, the Pt, impregnated tungsten, and nickel cermet samples were installed in the secondary emission (SEE) test vehicle for measurement. The secondary emission measurements are summarized in Table I. There is some indication from these data that the polished samples have a somewhat higher δ than the unpolished samples. An indication of the effect of sputtering on δ was obtained by scanning across the target surface, thus passing through sputtered and unsputtered regions on the same sample. Although the results are only considered preliminary, the indications are that sputtering tends to lower δ by up to 10% for the nickel cermet and impregnated tungsten samples. Sputtering had no discernible effect on δ of the Pt sample.

Some observations of fluorescence were also made in the case of the nickel cermet samples; the other samples did not show any fluorescence. There were differences between sputtered and unsputtered regions as well as between polished and unpolished samples of Ni cermet. These observations are summarized in Table II. The white spots observed in the unsputtered region of the polished Ni cermet samples were regions which had a high δ, and showed charging effects. It is supposed that the white spots contain BaO in the vacuum system after bakeout.

---

* Radio Mix No. 3 contains 60% Ba CO_3 and 40% Sr CO_3 by weight and has an average particle size of 5 to 6 microns.

** The separation is indicated by the superimposed diagonal line.

Sputtered

Unsputtered

Figure 5. Polished Cermet Sample Sputtered at 2 ma/cm^2 (80X Mag.)

TABLE I

Secondary Emission Ratio (δ) for Various Sputtered Samples

Sample	δmax, after system bakeout	δmax, after 1st heat treatment	δmax, after 2nd heat treatment
1. Pt, sputtered	1.64	1.95 (1000°C-10 min)	----------
2. Impregnated Tungsten (4-1-1), sputtered	2.30**	5.52** (1050°C-15 min)	3.24** (1050°C-15 min)
3. Impregnated Tungsten (3.5-1-1), sputtered	1.76	2.66 (1050°C-15 min)	2.66 (1050°C-15 min)
4. Ni cermet,* unpolished, sputtered	1.50	1.84 (850°C-10 min)	2.06 (900°C-10 min)
5. Ni cermet,* polished, sputtered	1.91	3.00 (850°C-10 min)	2.84 (1000°C-20 min)
6. Ni cermet,* polished, unsputtered	1.84	3.00 (850°C-10 min)	2.96 (1000°C-10 min)
7. Ni cermet,* unpolished, unsputtered	1.39	2.57 (850°C-10 min)	2.58 (1000°C-10 min)

* All four Ni cermets had the same composition (70% Ni, 30% Radio Mix No. 3) and same processing.

** This measurement refers to sputtered region only.

TABLE II

Fluorescence of Ni Cermet Samples

	Unsputtered region	Slightly Sputtered region	Highly Sputtered region
Polished Sample	greyish white background with white at white spots	no white spots, hardly any fluorescence	no fluorescence
Unpolished Sample	blue, no white spots	greyish white	no fluorescence

2.2.2 Semiconductors. One approach to the choice of a cold cathode material is the use of refractory semiconductors with high δ. In this case the electron bombardment dissociation processes would release non-volatile atoms (as contrasted with the oxygen which evolves from oxides). The hope is that electron bombardment would not cause the cathode material to deteriorate.

In line with this objective, several semiconductors were measured.

Measurements of the secondary emission ratio as a function of primary energy are shown in Figures 6 and 7 . The semiconductors GaAs, CdS, and CdTe shown in Figure 6 were obtained from the Raytheon Research Division, while the intermetallic compound, $Ti_{14}Ni_{48.5}Si_{37.5}$, was obtained from Professor Beck of the University of Illinois. Of these materials, GaAs appeared the most promising, having a maximum δ of approximately 3.5. It is possible that an excessive amount of As may be evolved on heating GaAs to tube bakeout temperatures, however the GaAs cathode could be cooled if necessary.

2.2.3 Metal-Alumina Composites

Another type of material being considered in the present program is the metal-insulator composite of which the metal alumina composite is a significant sample. The metal component provides conductivity while the alumina is responsible for the high δ. Two samples of this type of candidate material were worked on during the present quarter. These were:

1. "Linde B" Al_2O_3 powder compact wherein each particle is coated with a very thin layer of Ag.

2. Residual slugs of molybednum-alumina used as sources for electron beam evaporation.

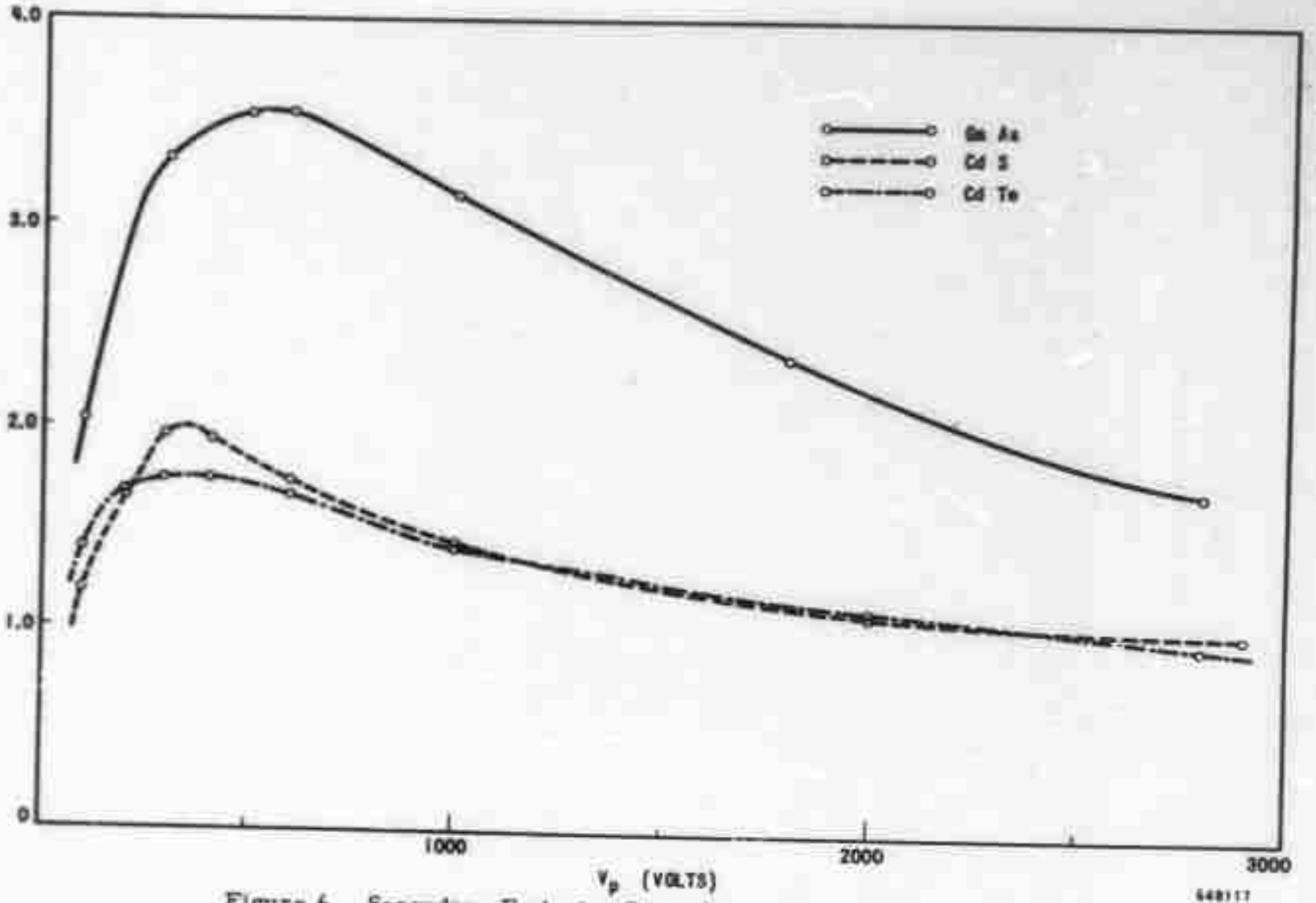

Figure 6 Secondary Emission Ratio (δ) vs Primary Energy (V_p) for Several Semiconductors

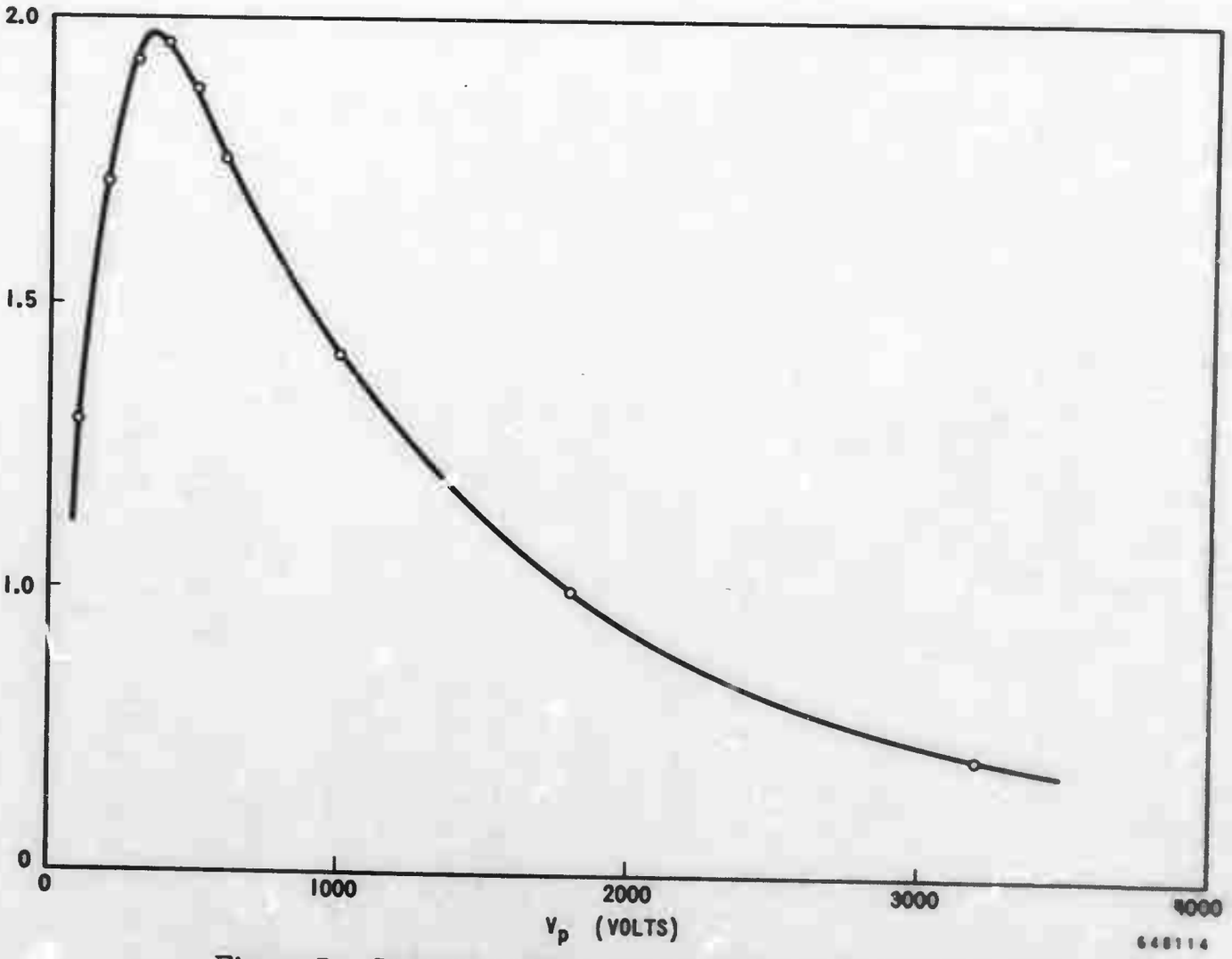

Figure 7 Secondary Emission Ratio (δ) vs Primary Energy (V_p) for $Ti_{14}Ni_{48.5}Si_{37.5}$

The compact of Ag-coated Al_2O_3 particles was pressed and fired in N_2 at 600°C for one half hour. It was then placed in the IBV in order to sputter off any surface layers of Ag to reveal the high δ Al_2O_3. The sample resisted sputtering, indicative of an insulating surface. However, the subsequent measurement of secondary emission in the SEE vehicle did not show any charging effects. The observed maximum value of δ was 1.45 at 500 volts after system bakeout, and 1.57 at 500 volts after a further 15 minute heat treatment at 400°C.

Three molybdenum-alumina slugs were used, having an initial composition of 10%, 20%, and 30% molybdenum. All the slugs showed a resistance to sputtering. The measured values of δ were as follows:

Sample	δmax after system bakeout	δmax after 15 min at 400°C
10% Mo - 90% Al_2O_3	2.02	1.64
20% Mo - 80% Al_2O_3	1.73	1.64
30% Mo - 70% Al_2O_3	1.72	1.87

No charging effects were observed during the secondary emission measurements. So far, the metal-alumina composites tried have had too low a secondary emission ratio.

2.2.4 Boron Nitride

A 200Å CVD film of boron nitride* was found to have a high δ. Following are the results of the measurements:

Treatment	δmax	$V_{p\,max}$ (volts)
After system bakeout	4.86	425
15 min at 400°C	5.82	350
Additional 15 min at 400°C	6.44	375
Additional 15 min at 400°C	5.75	400
Additional 15 min at 400°C	4.30	400
Additional 15 min at 400°C	3.83	400
Additional 15 min at 400°C	4.32	400

Figure 8 shows the measured dependence of δ on V_p after the last heat treatment. Based on the experience with molybdenum-alumina films one may suppose that it is possible to dope the BN film to achieve a desirable conductivity without seriously degrading δ.

* The sample was prepared in the Raytheon Research Division under the direction of Dr. W. Feist.

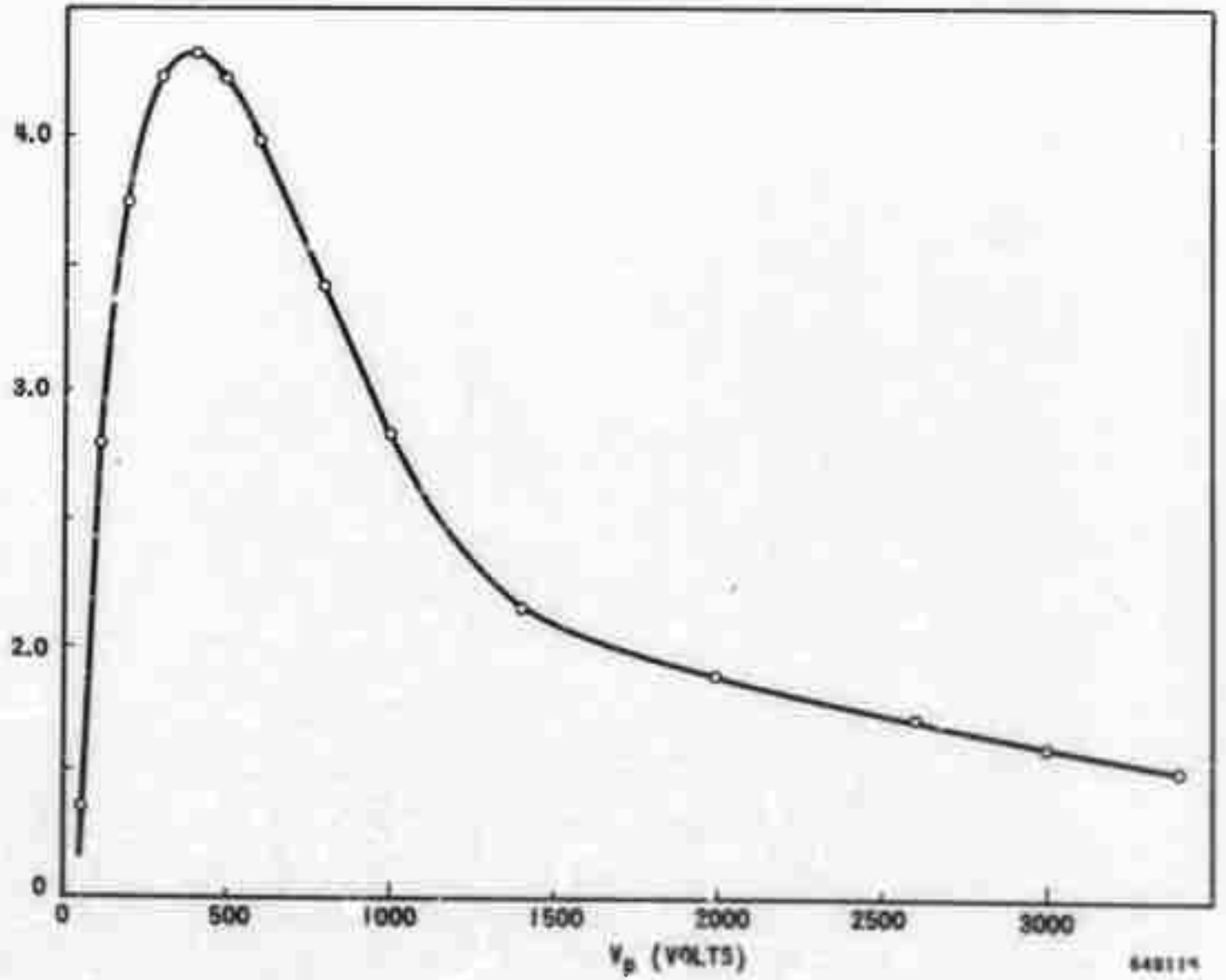

FIGURE 8 Secondary Emission Ratio (δ) vs Primary Energy (V_p) for BN

2.3 Electron Bombardment Investigation

2.3.1 Molybdenum-Alumina Films. An extensive investigation was made in the Electron Bombardment Vehicle (EBV) (See Figure 9) of the effects of electron bombardment on a 500 Å thick 30% Mo - 70% Al_2O_3 film on a Mo substrate. The deactivation of the film was due to continuous electron bombardment at 0.5 Amp/cm^2 and at 1.0 Amp/cm^2, both at 1200 volts. The reactivation of the film was accomplished by the use of an auxiliary oxygen source. CuO powder was pressed into the shape of a pellet and trapped at the end of a molybdenum cylinder inside of which a tungsten heater was mounted. Thus the oxygen partial pressure in the vacuum system could be controlled by adjusting the temperature of the CuO pellet.

The data for the Mo-Al_2O_3 film shown in Figure 10 represents a typical segment of the activation-deactivation procedures performed. Electron bombardment at 0.5 Amps/cm^2 caused a deactivation of δmax from 3.8 to 3.2 in 3 hours. The oxygen source was then turned on to a CuO pellet temperature of 560°C. This corresponded to an oxygen partial pressure of 7×10^{-8} Torr.* The secondary emission ratio (δ) recovered partially while bombardment at 0.5 Amp/cm^2 continued. More complete recovery was achieved at an oxygen pressure of 6×10^{-7} Torr. Recovery of δ was also observed to occur while the equipment was turned off overnight. This is attributed to reoxidation of the surface; the oxygen may come from other tube surfaces or from deeper sites within the cathode. Again, as seen in Figure 10, the deactivation of the Mo-Al_2O_3 film was more rapid for electron bombardment at 1.0 Amp/cm^2, a decrease in δmax from 3.4 to 2.6 occurring in 3 hours. Recovery was observed using oxygen at a pressure of 6×10^{-7} Torr. The recovery was only partial; presumably a higher oxygen pressure is needed to maintain δ under higher current density electron bombardment conditions.

2.3.2 Platinum

A Pt sample was mounted in the EBV to serve as a reference point in the secondary emission measurement in the EBV and also to investigate the effect of barium evaporation from the impregnated tungsten cathode of the electron bombardment gun. Secondary emission data for the Pt target in the EBV is shown in Figure 11. It can be seen that δmax was about 15% lower than the usual value of 1.8, measured repeatedly in this laboratory.

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* A calibration of oxygen pressure as a function of CuO pellet temperature yielded the expected exponential dependence $P = P_0 \exp(-Q/kT)$ with an activation energy of 220 kilocalories per mole.

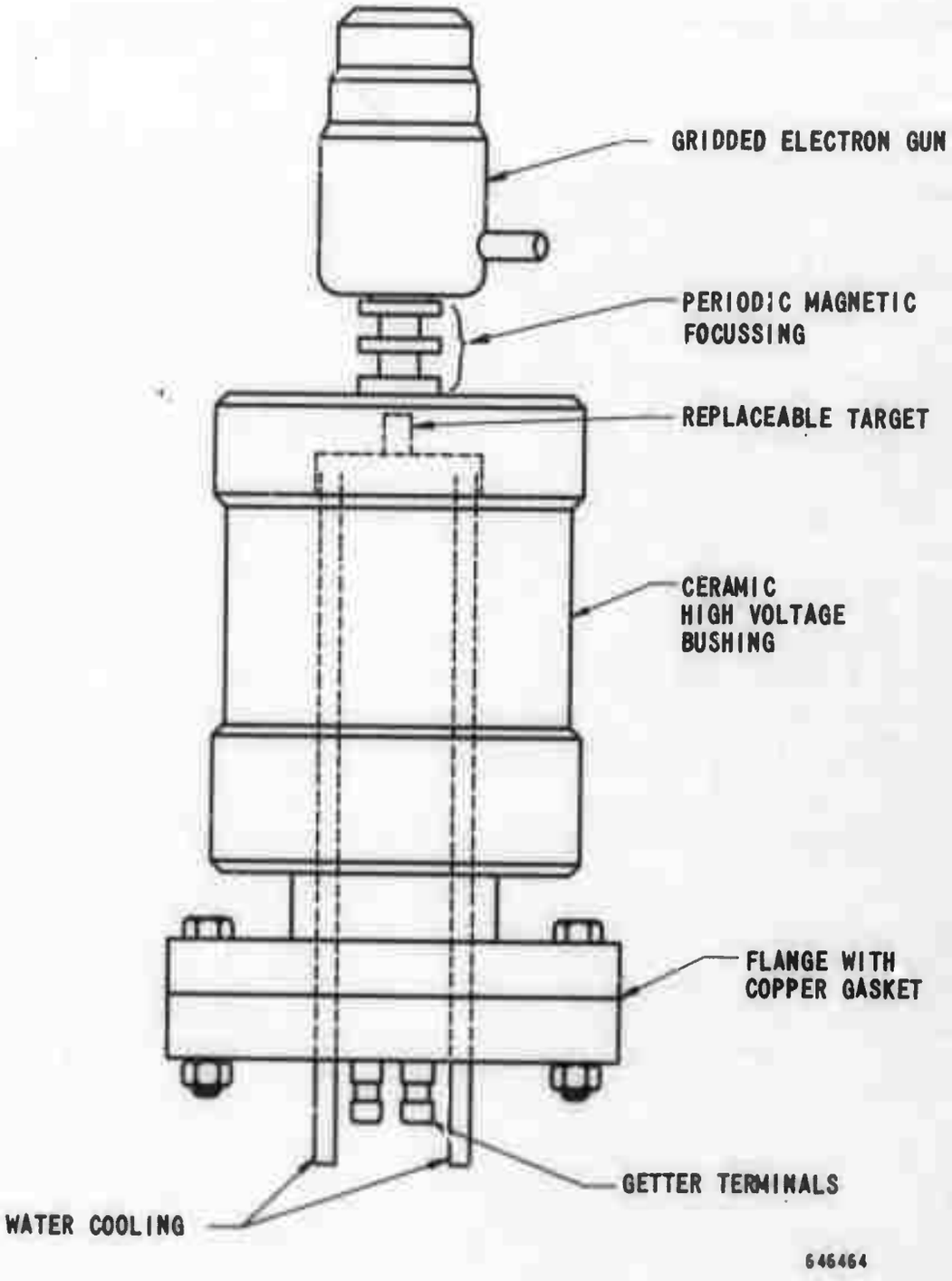

Figure 9 Electron Bombardment Vehicle

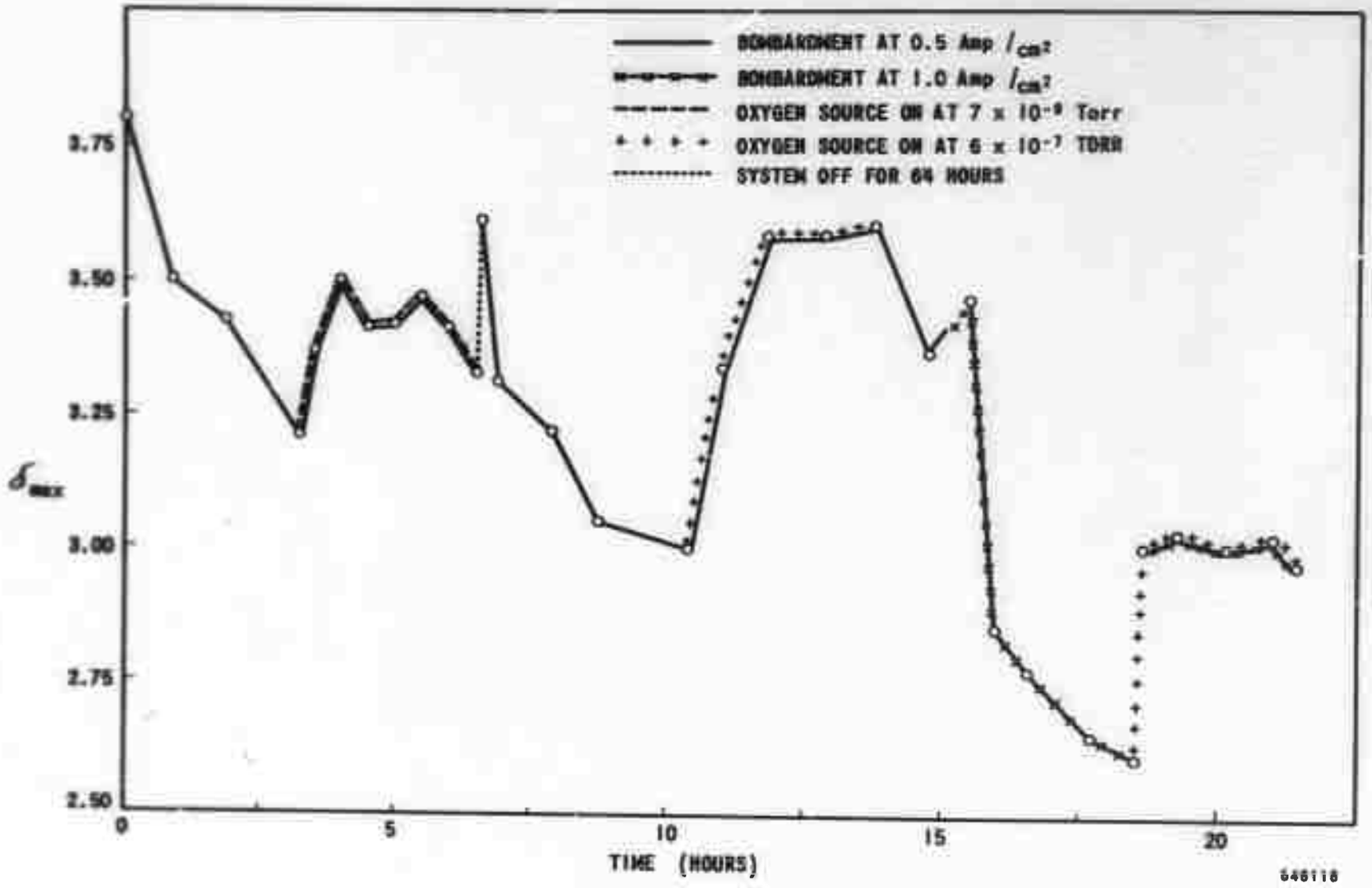

Figure 10 Activation of 500 Å 30% Molybdenum - 70% Al_2O_3 Film on Molybdenum Substrate using CuO Oxygen Source

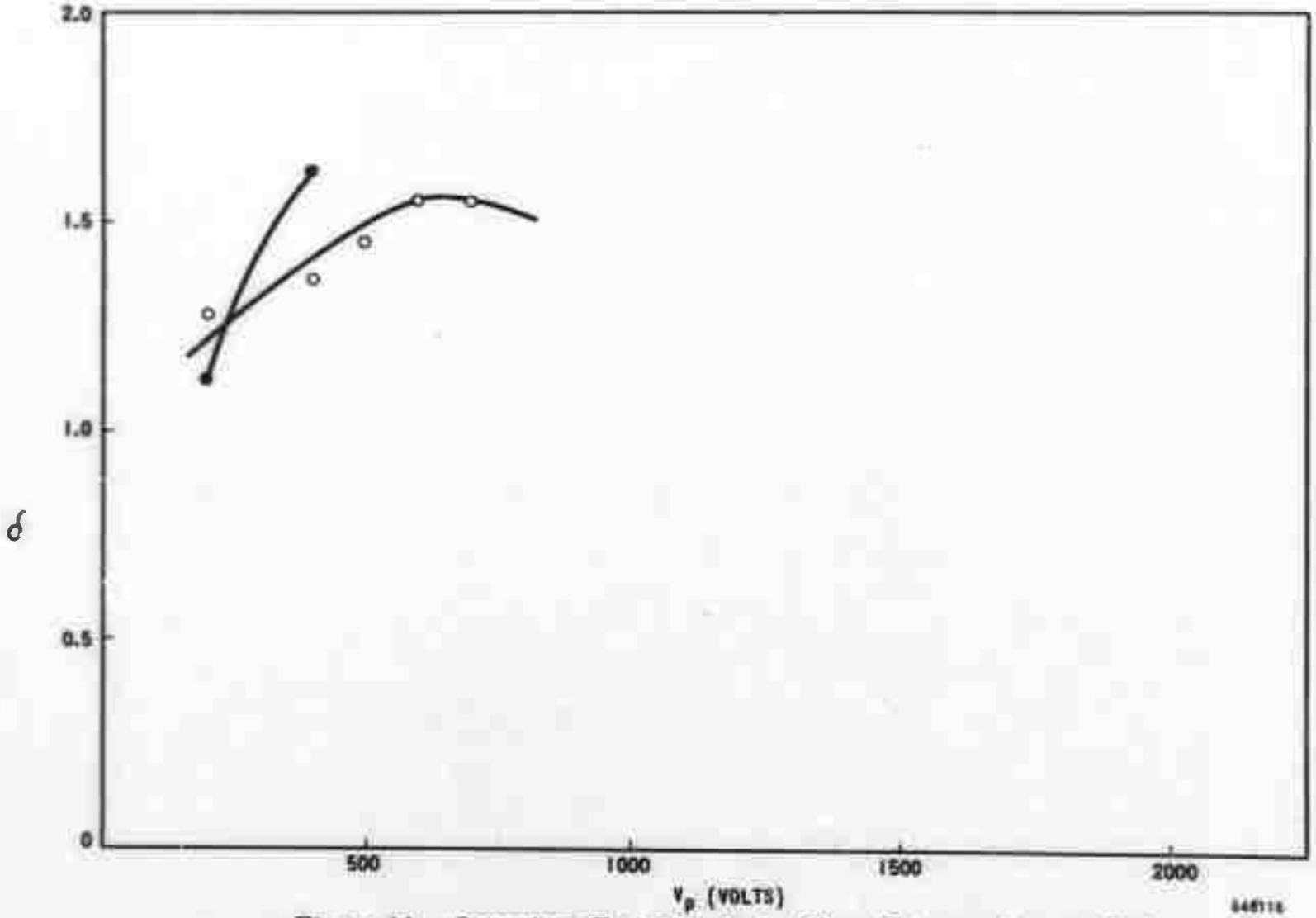

Figure 11 Secondary Emission Ratio (δ) vs Primary Energy (Vp) for Pt in EBV

It was also observed that electron bombardment at levels of up to 0.5 Amp/cm^2 at 1200 volts over a period of several hours had no effect on δ of the Pt target. In addition EBV gun cathode temperature changes from approximately 1025°C to 875°C resulted in no change of δ. This temperature change corresponded to a change in Ba evaporation of at least a factor of 10. It is concluded that Ba evaporation from the gun cathode does not play a significant role in the δ measurements reported in the EBV.

2.4 Electron Diffraction Analysis of Molybdenum-Alumina Films. Secondary emission measurements (See Figure 12) showed the importance of the substrate temperature during film deposition. The secondary emission ratio decreased by a factor of 2 as the Mo substrate deposition temperature was varied from 600°C to 1100°C for the 1000Å thick 30% Mo-70% Al_2O_3 films. It was therefore of interest to determine any differences in film structure or composition to correlate with the δ changes.

Electron diffraction patterns were obtained from two 1000Å films of 70% Al_2O_3/30% Mo deposited at 600° and 1100°C respectively, onto molybdenum substrates.* Diffraction rings representing polycrystalline material were obtained from both specimens, and the following conclusions were drawn from the patterns:

a) 1100° Evaporation

1) The diffraction rings were moderately sharp, suggesting sizable crystalline areas, probably containing at least several hundred atoms?

2) Seven of the rings represent d-spacings which are in good agreement with those for elemental molybdenum, as listed in the ASTM file.

3) The remainder of the rings do not, as a group, match any single Al_2O_3 pattern, although each individually approximates a d-spacing for one of the various alumina structures. Nor do they agree with any other single phase pattern in the ASTM file. Since it is thermodynamically unlikely that any reaction products of Mo and Al_2O_3 have formed, it is probably safe to assume that these additional rings were caused by some form of aluminum oxide, possibly a mixture of several allotropes.

b) 600° Evaporation

1) The diffraction rings were fewer in number than those for the 1100° specimen, and more diffuse, indicating a lower degree of crystallinity.

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* The electron diffraction work reported in this section was performed by W. R. Bekebrede of Raytheon's Research Division.

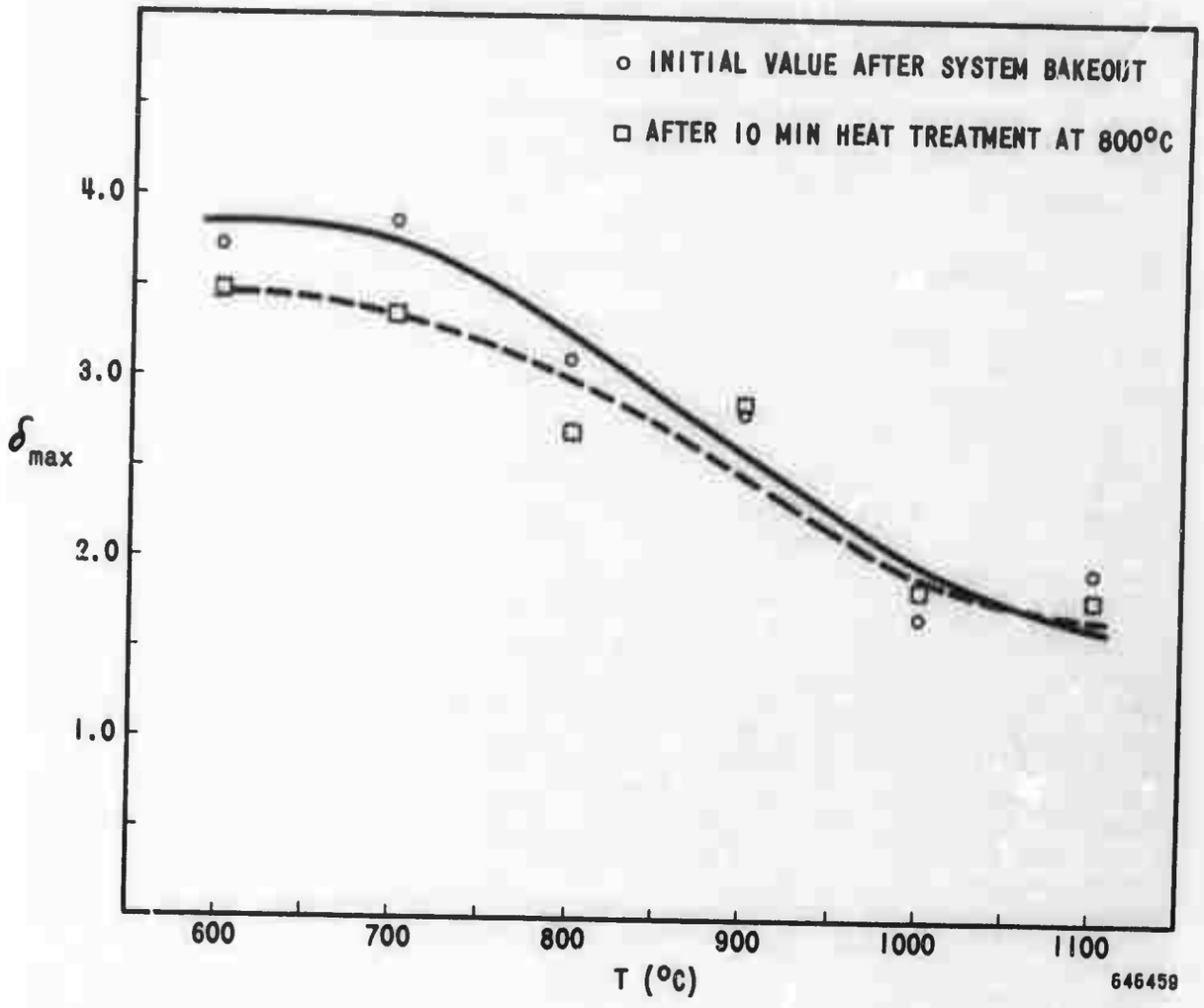


Figure 12 Secondary Emission Ratio Maximum (δ_{max}) vs Substrate Temperature at Deposition for 1000 Å Mo - Al_2O_3 Films on Molybdenum Substrate

2) No molybdenum rings were present, suggesting a high degree of dispersion of the Mo atoms in the film. This also provides evidence that the molybdenum pattern mentioned above is not due to the underlying molybdenum substrate but does arise from the film itself.

3) As above, the rings are not in agreement with any single pattern but are not inconsistent with the assumption of a mixture of Al_2O_3 phases.

It can be seen from the above analysis that increases in the size of agglomerated molybdenum particles, for sizes up to approximately several hundred atoms, decreased δ to values which more nearly approach δ of the molybdenum phase.

3. PHASE B - CFA TESTING

3.1 Evaluation of a 1000Å Molybdenum-Doped Alumina Emitter - TV No. 1C. The evaluation of this emitter was completed during this report period with emphasis placed upon the deteriorating effects of electron bombardment dissociation (EBD), sputtering, and arcing conditions on cold cathode emission. Plots of Operating Gauss Line data are shown in Figure 13. Plots of the repeated low field emission current boundary data exhibit emitter depletion as shown in Figure 14. Initial low field emission current boundary data are shown in Figure 15 which is repeated from Quarterly Report No. 2 for convenience.

Sputtering, EBD, and arcing can be produced by various combinations of current, magnetic field, and high voltage, while observing the visual display through the four viewing ports. Sputtering is believed to occur in the presence of a "blue glow" which occupies the entire interaction space volume and is always present when the CFA is in its proper amplification mode. Arcs appear as small bright spots which occur more frequently and increase in intensity at higher voltage levels. In order to separate out the effect which each produces upon emitter deterioration, the CFA was run well below the arc boundary for a specified length of time with continuous visual monitoring of the viewing ports. If an arc was observed during a test, the data was not considered representative of the effects of sputtering and EBD alone. Controlled arcing runs were produced by raising the high voltage and allowing the tube to arc for specified intervals of time (limited to approximately 2 minutes because of possible damage to the test vehicle anode). In this short period of time, it was possible to note a slight change in the emission current boundary data; however 20 to 30 minutes of continuous operation was required to detect emission depletion in the presence of EBD and sputtering alone. After several test runs of various time intervals with increasingly severe arcing and sputtering conditions, the data yielded conclusive evidence that a faster rate of emitter depletion occurs in an arcing environment.

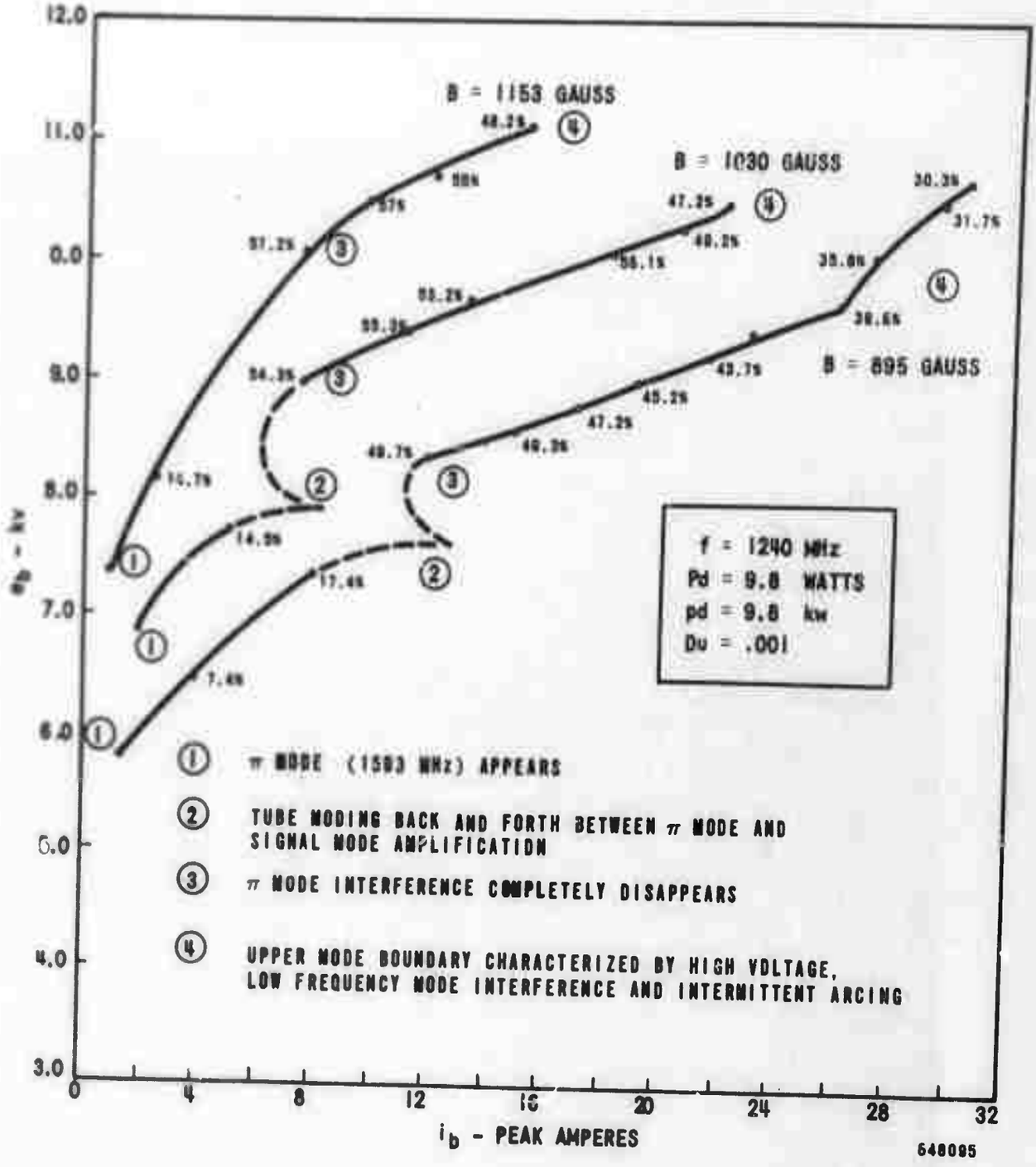


Figure 13 Operating Gauss Lines Cold Cathode Study
TV No. 1C (1000 Å Mo Al_2O_3 Emitter)

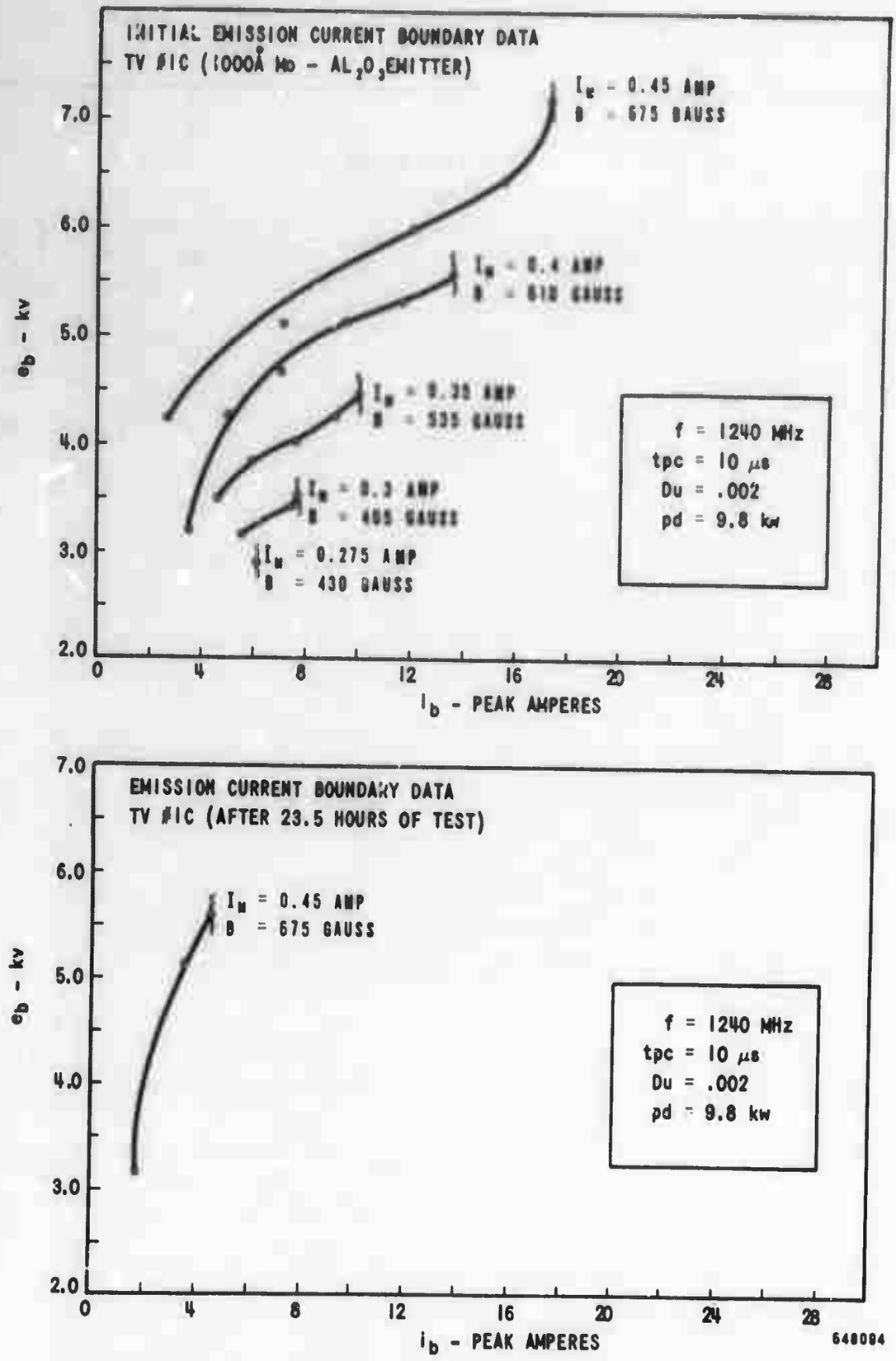


Figure 14 Emission Current Boundary vs Time
Cold Cathode Study TV No. 1C

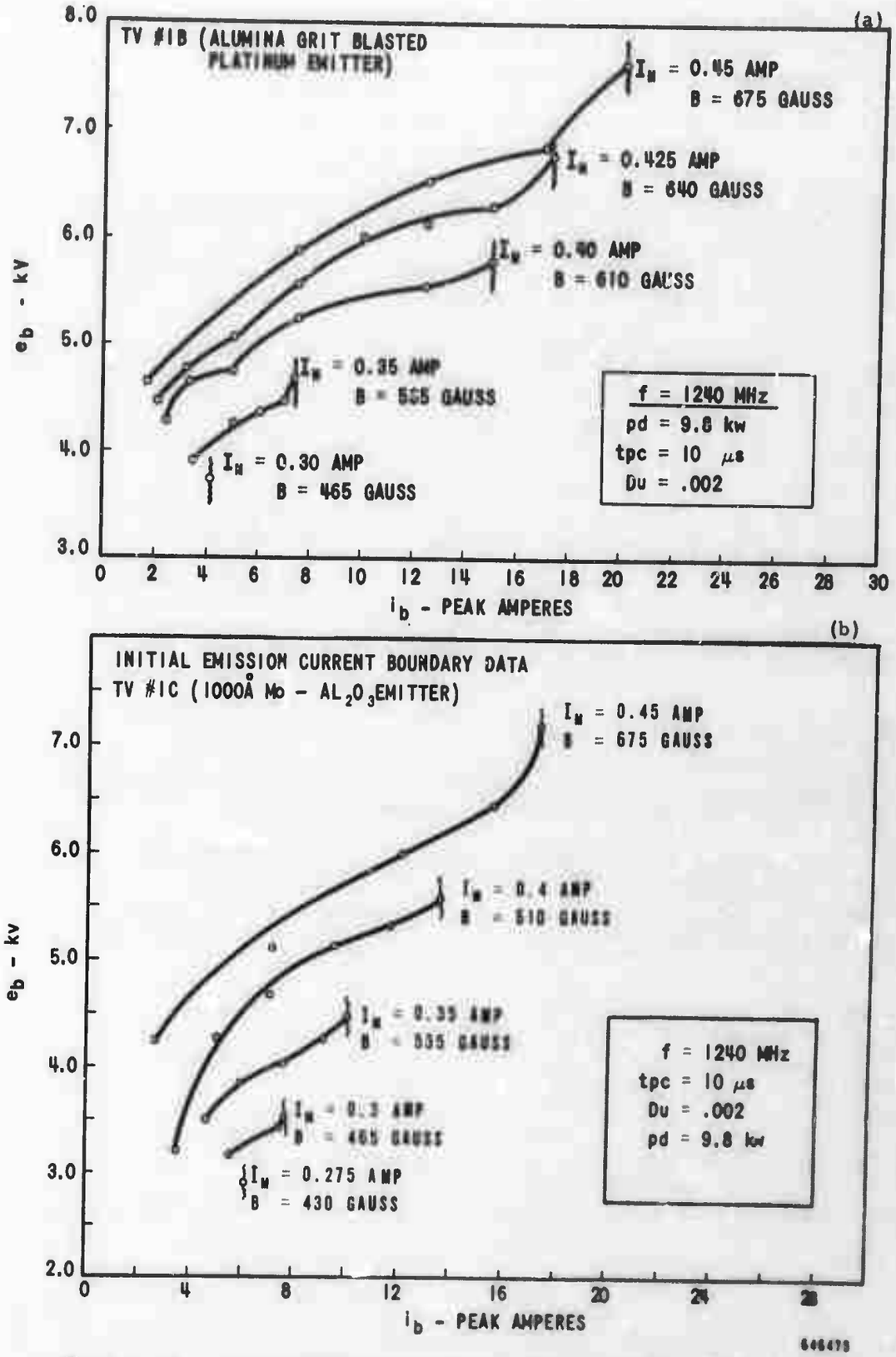


Figure 15 Comparative Low Gauss Emission Boundaries Cold Cathode Study TV No. 1B and No. 1C

Both sputtering and electron bombardment decomposition may contribute to the degradation of δ as evidenced by the shift in emission current boundary. EBD would cause the surface to be enriched in aluminum content due to oxygen evolution. It was suspected that the EBD mechanism was more significant than sputtering in the observed loss of δ. In order to confirm this supposition, it was decided to break open the exhaust tubulation, exposing the emitter surface to air and rebake the tube in an effort to restore the original current boundary conditions. The test vehicle was designated TV No. 1D. The comparative initial emission current boundary data for TV No. 1C and No. 1D shown in Figure 16 demonstrate increased emission current almost to the initial values obtained for the original 1000 Å Mo alumina emitter.

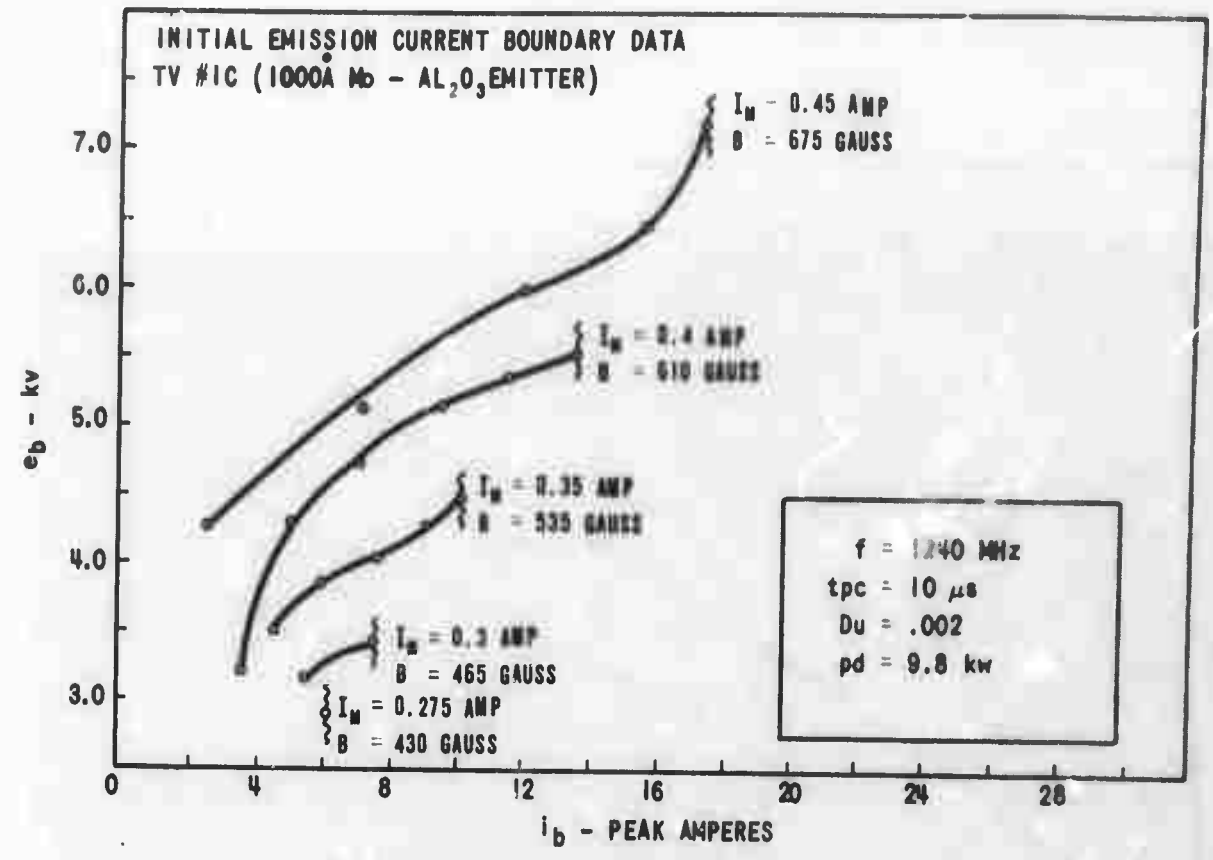
Since the natural oxide layer on aluminum is only approximately 25Å thick, the almost complete recovery of δ due to air exposure is interpreted to mean that EBD depletion in the first 25Å of the surface is the most important in degrading δ. This is consistent with previous measurements in this laboratory which showed a lack of dependence of δ on the thickness of the oxide layer on aluminum for the range 25Å to 1000Å.

3.2 Evaluation of Beryllium Emitter - TV No. 2. Another CFA test vehicle, designated TV No. 2, was equipped with a beryllium emitter and subjected to a series of evaluation tests. The results of the low field e.c.b. tests are shown in Figure 17 and the initial e.c.b. data compare favorably with the aluminum emitter. The effect of continuous CFA high voltage operation on emitter depletion is also shown in Figure 17.

After 37 hours of high average power operation, the tube was exposed to air and baked out in the same manner as the 1000Å Mo-doped alumina emitter. Low-field emission current boundary data show that almost 100% of the original current value was restored, supporting similar data for the 1000Å Mo-doped alumina cathode.

3.3 Investigation of Oxygen Source for Longer Life. It was appropriate to provide a continuous source of oxygen during CFA operation to obtain conclusive information on the natural oxide emitter depletion which had been observed.

While evaluation tests of the beryllium emitter were in progress, a method for providing a continuous source of oxygen during CFA operation was devised and the design and construction of associated hardware completed. The oxygen source consisted of a disc of pressed and sintered cupric oxide placed in a container which was provided with a heater. An experimental test was performed to determine partial pressures of oxygen as a function of heater power. The design of the oxygen source was incorporated into TV No. 2A and an 1100 series high purity aluminum cathode sealed in. Effort was concentrated on the evaluation of the oxygen source as one possible method of retarding, or preventing, the degradation of oxide surface layer emitters.



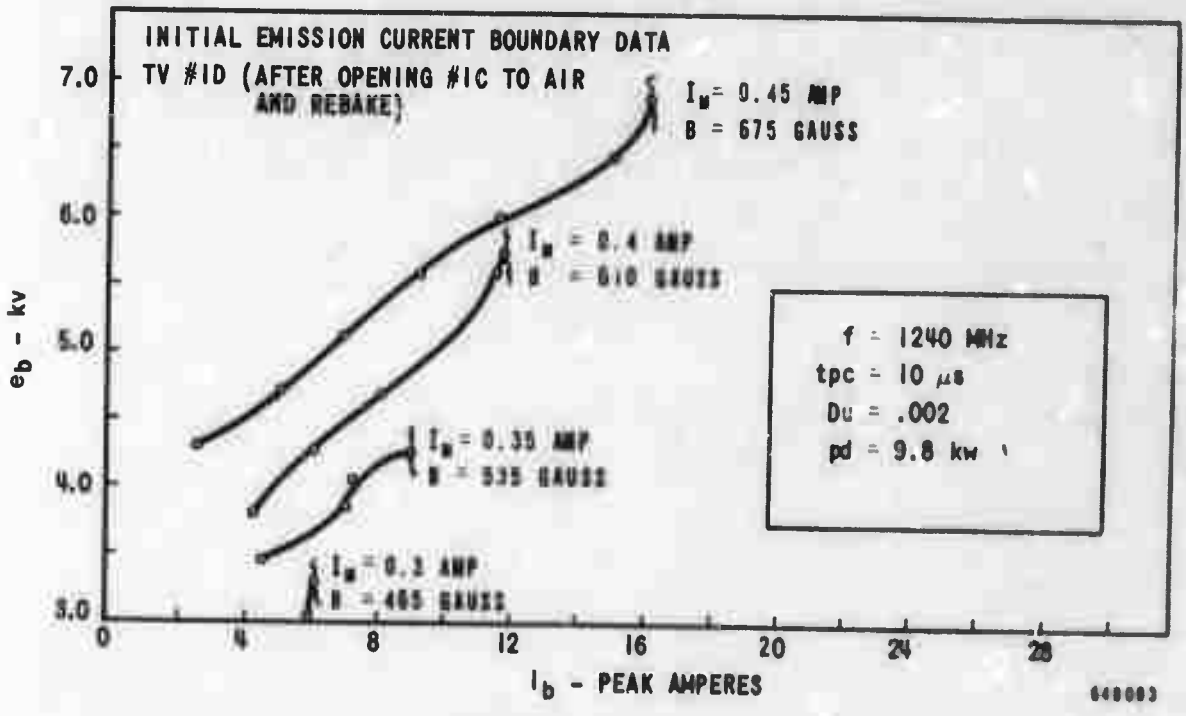


Figure 16 Comparative Initial Emission Current Boundaries Cold Cathode Study TV No. 1C and No. 1D

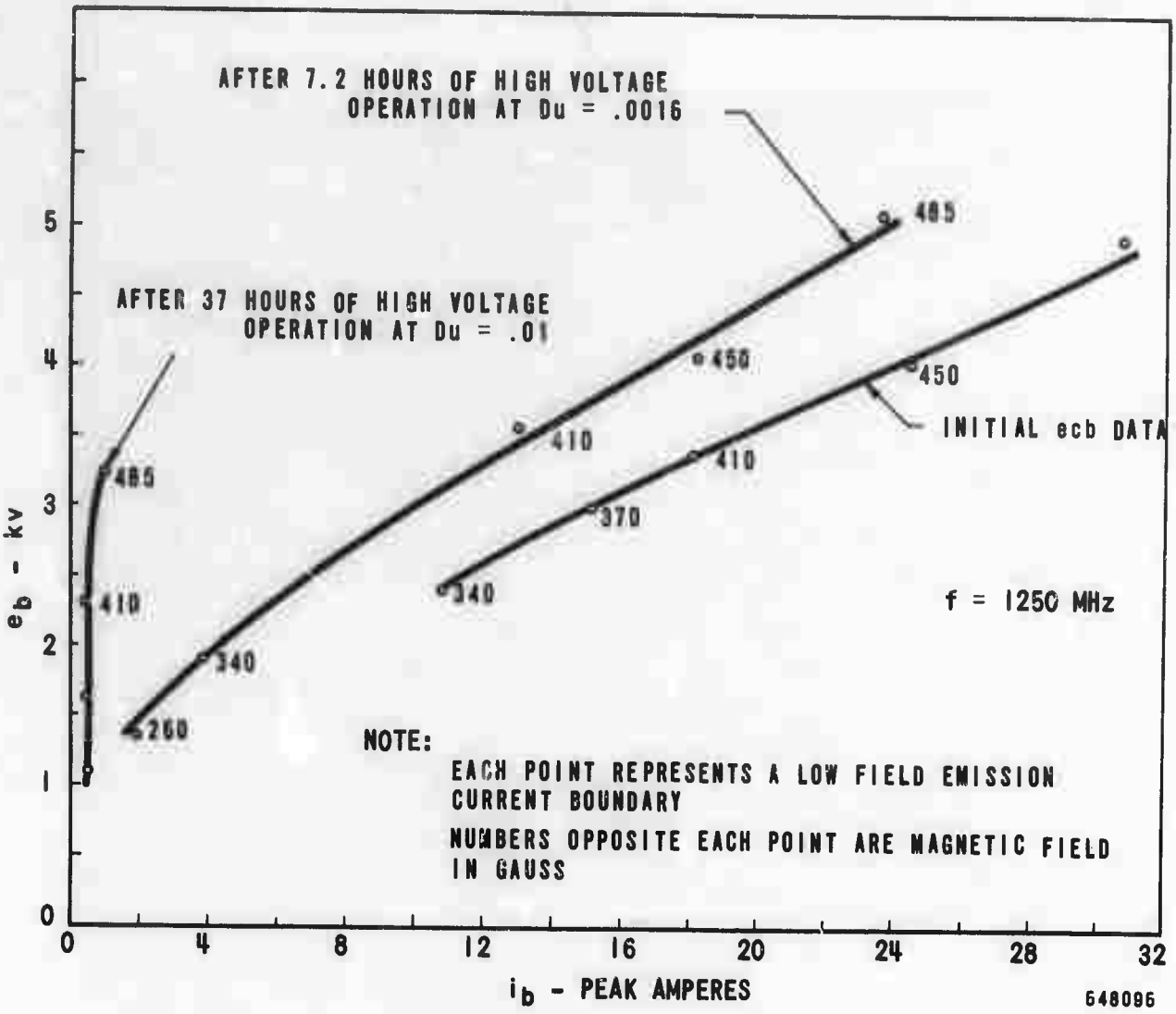


Figure 17 Low Field Emission Current Boundaries vs Time
TV No. 2 (Beryllium Emitter)

Unfortunately, in the early stages of testing, an arc occurred which caused the control electrode high voltage lead to become open circuited, eliminating pulsed control electrode operation with the dc supply. It was possible, however, to achieve high average power operation by increasing the pulse width and repetition rate while testing in the cathode pulsed modulator.

The conditions listed below remained constant throughout the oxygen source evaluation:

Frequency	1300 MHz
tpc	78 μs
duty cycle	0.0156
peak drive	4.5 kw

Figure 18 shows the effect of O_2 on CFA emission current boundaries as observed in T.V. No. 2A.

The following conclusions were made after examination of the data:

1) Oxide film dissociation occurred during CFA operation, probably due to electron bombardment.

2) A source of oxygen retarded the depletion rate of this type of emitter.

3) Emission improvement was more rapid with the high voltage off.

4) Although it was not possible to sustain a high emission level with constant heater power to the oxygen source, improvements in some of the oxygen source design features and oxygen balance factors appear possible.

A considerable increase in heater power was required to achieve partial pressures of oxygen comparable to previous experimental data, however this may be attributed to increased heat conduction paths away from the oxygen source which were the result of a design revision necessary to incorporate the assembly into the tube. The mechanical design of the heater source and cup have been changed and parts are now being assembled.

3.4 Summary. Platinum cathodes whose emitter surfaces have been treated with alumina particles, the Mo-doped alumina cathode and the natural surface-oxide beryllium and aluminum emitters have all initially produced sufficient current for efficient CFA amplification. The platinum, beryllium, and alumina cathodes have been evaluated at high duty cycles and wide pulse widths initially producing high average power output with control electrode pulsing.

All have demonstrated rapid emission deterioration rates which can be traced to oxide depletion believed to be due to electron bombardment. The provision of a continuous oxygen source may be a practical means of eliminating or significantly retarding the deterioration.

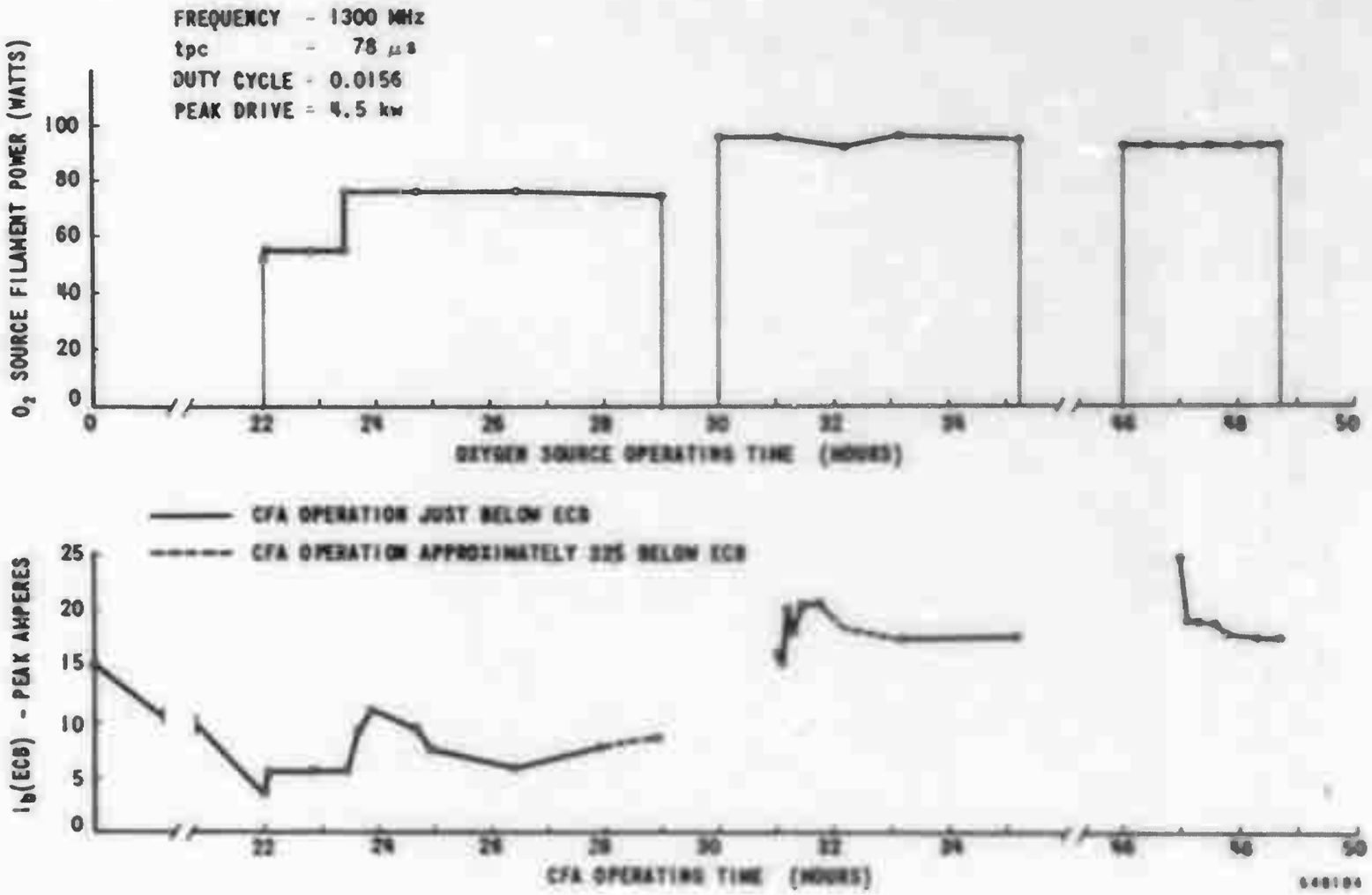


Figure 18 Effect of O_2 on CFA Emission Current Boundary

4. LITERATURE CITED

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2. Germer, L. H. and White, A. H., Phys. Rev. 60, 447-454 (1941).

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13 ABSTRACT

Examination of samples sputtered in Ion Bombardment Vehicle, as well as measurement and observation of samples in Secondary Emission Test Vehicle, led to following conclusions: 1) 30% Mo - 70% Al_2O_3 films on Mo substrate exhibited sputtering rate of 0.007 molecules of Al_2O_3 per nitrogen ion; 2) Two hours of N_2 sputtering of impregnated tungsten sample increased apparent porosity of surface from 15% to 47%; 3) Sputtering had no effect on δ of Pt, while sputtering for 1-2 hours reduced δ for nickel cermet and impregnated tungsten samples.

Maximum secondary emission ratios (δ) of 3.5 and 4.3 were measured respectively for GaAs and 200Å CVD BN samples.

Measurements in Electron Bombardment Vehicle (EBV) demonstrated: 1) Secondary emission ratio maximum of 3.6 was maintained for 500Å thick 30% Mo - 70% Al_2O_3 film on Mo substrate, under electron bombardment by maintaining oxygen partial pressure using CuO oxygen source; 2) δ measurement in EBV is low and is not affected by barium evaporation from impregnated tungsten gun cathode.

Electron diffraction measurements showed δ of Mo - Al_2O_3 film was reduced by agglomeration of Mo component to aggregates several hundred atoms in size.

Preliminary evaluation of auxiliary oxygen source in CFA test vehicle with aluminum cathode demonstrated: 1) Oxygen removal from cathode surface during tube operation causes degradation of δ; 2) Auxiliary oxygen source retards cathode depletion rate; 3) Cathode activation due to oxygen rapid with high voltage off; 4) Depletion rate during CFA operation faster than EBV under electron bombardment.

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KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Sputtering						
Secondary emission (δ) ratios						
Electron bombardment						
Mo - Al_2O_3						
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